CENTER PIVOT IRRIGATION SYSTEM FOR SITE-SPECIFIC WATER AND NUTRIENT MANAGEMENT

by

C. R. Camp
Agricultural Engineer

E. J. Sadler
Soil Scientist

U.S. Department of Agriculture, Agricultural Research Service
Florence, SC

Written for Presentation at the
1994 International Winter Meeting
Sponsored by
ASAE

Atlanta Hilton & Towers
Atlanta, GA
December 13-16

Summary:

Site-specific water and nutrient management for southeastern Coastal Plain soils will be provided by a commercial center pivot modified to allow programmable management. A multiple-segment water delivery system along the lateral will provide variable water and nutrient application rates without changing tower velocity. A prototype 10-m segment has been evaluated for uniformity, for control system operation, and for conformance with design pressures and flow rates. The developed system should improve water and nutrient efficiencies and reduce the potential for environmental contamination by chemicals.

Keywords:

Center pivot, Irrigation water management, Site-specific crop management, Nutrient management

INTRODUCTION

The coarse-textured soils of the southeastern Coastal Plain often exhibit greater variability within comparable field sizes than do soils of other regions, especially the fine textured soils of the midwestern plains and western valleys. This spatial variability is characterized by differences in soil texture, water characteristics, organic matter content, depth to clay, inherent fertility, and extent of layering in the soil profile. Many of these variables affect water and nutrient availability, which severely complicates management of these soils in a cropping system, especially when the highly variable rainfall (both spatial and temporal variation) of the region is considered. Optimum management of irrigation and nutrients when applied via an irrigation system is often not possible for even relatively small center pivot or linear irrigation systems because of soil variability within the system area and inability of the system to alter application rates to coincide with small, irregular boundaries.

A research study that investigated crop yield for 12 crops during a 9-year period in the southeastern Coastal Plain found there was almost as much yield variation within soil mapping units as among mapping units. This study was conducted on a 24-ha area where the soils had been classified by USDA-SCS, who started with a 15-m grid and moved to a finer resolution when needed to identify soil map unit boundaries. Both statistical regression and mechanistic modelling were unsuccessful in explaining the yield variations. Geostatistical analysis produced expected patterns of high and low yield, but year-to-year variation in mean yield masked underlying patterns. A method using normalized annual yield variation produced composite maps of relative yield and could be useful in setting target yields of various soil types and calculation of fertilizer requirements. Interpretation of these results and extension of the information to make fertilizer and irrigation recommendations depends on the quantitative description of causes of variation among soils. Despite problems encountered, mechanistic simulation models appear to be the most likely tool to achieve this objective (Sadler et al. 1994). These quantitative descriptions will be required for the proper operation of site-specific irrigation systems.

Several irrigation systems have been developed to improve precision and provide various levels of spatial control of water and/or nutrient applications. Lyle and Bordovsky (1981, 1983) developed the Low Energy Precision Application (LEPA) irrigation system that used a low-pressure linear irrigation system to distribute water via drop tubes directly into furrows with micro basins to limit surface water movement. Howell and Phene (1983) modified a linear irrigation system, to provide both laser alignment of towers and a low-pressure application system. They evaluated seven different delivery systems including two trickle drag line configurations; two below-canopy point sources; and three sprinklers: overhead, over canopy, and below canopy. Both of these linear systems (LEPA and laser-aligned) had modified tower drive systems that allowed variable-rate, continuous movement as opposed to the normal start-stop movement. Linear systems have been modified to also allow variable water application rates. Lyle (1992) used three manifolds, each delivering discrete but different flow rates, that could be used in various combinations to achieve a range of water application rates. Duke et al. (1992) modified a linear irrigation system to provide variable water and nutrient applications to multiple strips using pulsed sprinklers mounted on discrete manifolds along the truss. The water and nutrient application rate was determined by the rate at which the water supply to each manifold was pulsed via switching the solenoids on and off. Stark et al. (1993) reported the development of a control system for site-specific application of water and chemicals that could be used on linear and center pivot irrigation systems. This system used a microprocessor to control individual nozzles, lateral speed, and flow rate of the chemical injection pump according to a spatially-referenced mapping system. A U. S. Patent was awarded this system for variable rate application of irrigation water and chemicals (McCann and Stark, 1993).

Agricultural chemicals, especially nitrogen fertilizers, are often applied to crops via injection into the irrigation water during normal irrigation operations. Generally, chemical injection occurs at a single point where the necessary storage tanks, injection systems, and electrical power are available because the chemical is applied uniformly to the entire crop area. In a center pivot system, it occurs at the pivot. Chemical application at variable rates within an irrigation system would be very complex if the chemical application rate were not independent of the water delivery rate for the entire system. In these cases, either separate chemical delivery systems or multiple chemical injection points within the system must be utilized.

The objective of this research was to develop an irrigation system for site-specific water and nutrient applications. While the system will be used initially in research applications, it should have ultimate application in industry, possibly with some modification.

DESIGN CRITERIA

In 1991, a team was formed at the Coastal Plains Soil, Water, and Plant Research Center to determine specifications for an irrigation system that would provide spatially-controlled water and chemical applications in a research program concerned with water management and water quality. Initially, the team preferred a linear system because of the rectangular shapes of experimental plots and the total irrigated area, and the generally less complex sprinkler package required for variable-rate application. However, after consideration of the difficulties and errors associated with determining the location of all elements of the lateral (misalignment of towers and tracking error), of the need for portability of all support components, and of the potential applicability to commercial practice, the team decided to use a center pivot system. The basic requirement for the irrigation system was to apply water and chemicals to discrete areas within the system (about 100-m^2 area) based on soil, crop, and weather data stored in a data base or measured directly by sensors. Spatial location of each element of the water delivery system would be determined either by system operating parameters (angle of rotation, position along the lateral) or remote telemetry (e.g. global positioning system). When it became evident that it would not be possible to either obtain a system from commercial sources or to have one constructed via contract, the team decided to develop the system as a research project.

The general approach was to purchase a commercial center pivot system that provided as many elements of the desired specifications as possible, especially programmed control of tower speed and remote communication, management, and data transfer. The commercial system would be modified to provide the variable-rate water and chemical application system for discrete areas and other desired features. A schematic diagram showing commercially-available features, proposed modifications, and desired features for a center pivot system is included as Fig. 1. Initially, all control would be based on soil, crop, and weather data stored in a computer file. It was anticipated that later, measured soil and/or plant parameter values would be incorporated into the decision process to either re-initialize a simulation or to provide more precise spatial data.

A decision regarding the minimum area in which water and chemical applications would be controlled independently was required early in the planning process because it determined the manifold length along the irrigation lateral. In a center pivot system, the other dimension is determined by the angular resolution of the system, which, in most cases, is much finer than the desired control element size. The minimum control element size selected was 10 m along the lateral (manifold length) and an angular sector to provide an area of about 100 m^2, which requires a mean distance of 10 m in the direction of travel. Because a center pivot system was selected, a circular row culture was adopted. Consequently, the selected minimum control element would allow 10-12 standard rows about 10 m in length. While it would be much simpler to use a drip or bubbler water delivery system for each furrow or alternate furrows, a spray or sprinkler system was preferred. Because irrigated area is not linear with lateral length in a center pivot system (larger area for increased distance from center at a given rotational speed), sprinkler application rates must increase with lateral distance from the center. This range of rates must be incorporated into any variable-rate water and chemical application system. The desired range of irrigation application depths was 0 to 25 mm per revolution.

In commercial center pivot systems, the range of tower velocities is obtained via changes in the duty cycle of the end-tower drive motor (range of 0 to 100%). In some systems, the cycle period is selectable (e.g. 30 s or 60 s), which in connection with the cycle timer determines the actual on-time for the end tower. The duty cycle for interior tower drive motors is determined by the tower alignment system. In most systems, limit switches control the drive motor, energizing the motor when lateral misalignment at that tower lags by the preset limit and de-energizing it when the tower advances to the forward misalignment limit. During the energized period, the tower moves at a constant velocity determined by the motor speed, gear ratio, and tire size. Each interior tower operates independently of the system controller or cycle timer. This step-wise movement of the lateral has an undesirable effect on water and chemical application uniformity because the sprinkler moves at a constant velocity part of the time but otherwise remains stationary. This results in significant differences in water application to some areas, which depends very much on the specific sprinkler and its performance characteristics. Generally, the larger the sprinkler wetted diameter, the better the application uniformity for the step-wise movement and tower misalignment of commercial center pivot systems. Unfortunately, both the relatively short manifold length (10 m) of this modified system and the requirement to confine water and/or chemicals to the intended area severely limit the sprinkler wetted diameter and the selection of potentially acceptable sprinklers, especially at greater distances from the center. Modification of the tower drive system to provide a continuous but variable speed drive would improve application uniformity but would add complexity and cost to the system. Another concern is when the angular position of the lateral (measured at the pivot) and sprinkler location along the lateral are used to determine spatial locations within the system, lateral misalignment at each tower (unknown deviation from straight line) can contribute significant error to this position determination. For small systems such as the one used here (3 towers), this error is smaller that it is for large system with 10-12 towers where a bow-shaped lateral would cause accumulated rather than offset errors.

Although final decisions have not been made regarding all aspects of the control system required to achieve spatially-controlled water and chemical applications, the initial version of the system will probably utilize a microcomputer interfaced with a data base containing spatially-indexed soil and crop information. It will also be interfaced with the commercial center pivot management panel, and with a microprocessor-controlled switching system that controls water and chemical valves, pumps, and sensors. Initially, all components will probably be located on the center pivot irrigation system. Later, as communication technology either becomes available or more economical, components such as the data base and microcomputer may be located at a base station, which is remote to the center pivot system and could manage multiple systems. Similar technology is available on commercial center pivot systems today, but for much less complex data bases, for a much lower volume of communicated data, and at a much slower transmission rate. Significant volumes of information must be transmitted between the managing computer/data base and the microprocessor controlling the switching system. Also, the transmission rate must be high and the transmissions must be repeated at frequent intervals because many variables will be changing frequently (some continuously). Improvements in tower alignment and/or reduction in or compensation for error in position determination may be possible. Finally, feedback from measurements of soil and crop parameters as well as position determination can be used to improve management of the system and increase accuracy of water and chemical applications.

PROGRESS

Two commercial, 3-span center pivot systems with microprocessor-controlled management systems were purchased and installed in October 1993. Each system consists of one span 39 m long and two spans 48.8 m long, providing a total lateral length of 136.6 m and an irrigated area of 5.9 ha. The two irrigation systems were installed in a portion of the area where Sadler et al. (1994) conducted the soil variability research discussed earlier; consequently, a significant amount of information has been assembled regarding the management required for these soils. A schematic diagram showing the two center pivot systems and the various soil mapping unit boundaries is included as Fig. 2. Each system has an individual microprocessor-controlled management system that allows programmed operation and communication via radio to a base station where both systems can be monitored, controlled, or programmed remotely. The water supply for both systems is a pressurized water line (about 275 kPa) where the pressure and flow rate are automatically regulated. Water is pumped from a well into a lined reservoir and from the reservoir into the pressurized line via a variable-rate pumping plant. Both systems have two sprinkler packages, one with overhead spray nozzles and one with LEPA quad sprinkler heads on drops. Both sprinkler packages can be spaced either 1.5 m or 2.0 m apart to coincide with rows with the same spacings.

A third water application system will be installed on both systems to provide variable-rate water and chemical applications for a given tower speed. The modified water application system is being developed in cooperation with University of Georgia at Tifton. The first system, to be installed on one of the center pivot systems, will probably consist of three manifolds for each 10-m section along the lateral, with each manifold delivering a different rate. The manifolds will be controlled individually so that they can be pressurized to provide eight combinations of application rates (0 - 7). It is not yet known whether a satisfactory spray or sprinkler system can be developed. If acceptable application uniformity cannot be achieved or if the control width of acceptable uniformity is not a significant part of the total width, an alternate system using a range of orifices will be installed to provide the appropriate application rates. Discharge from three orifices (one for each manifold) will be collected in a drop tube and discharged immediately above the soil surface in alternate furrows, probably at a spacing of 2 m.

A PLC system consisting of a controller and the appropriate analog and digital relays is being configured for installation. A separate microcomputer, which communicates with the controller via the system bus, and an associated hard disk drive will store and retrieve spatially-indexed data, receive positional data from the center pivot management system, interpret management parameter values provided by the user, formulate instructions for water and chemical applications, and transmit a set of codes to the PLC controller. Initially, all of these components will be installed on the center pivot system. Use of the commercially-available transmission capability between the center pivot management system and the base station is not expected at this time because of slow transmission rate and the requirement for extensive software modifications. It may still be possible to monitor system status from the base station, but this is not known at this time. However, communication between the microcomputer and both the PLC controller and center pivot control panel will be necessary. These communication protocols have been investigated but have not yet been tested in the field.

Extensive software development will be required for successful operation of the control system. A Cooperative Research and Development Agreement (CRADA) with the center pivot system manufacturer, Valmont Industries, should facilitate development of this software, especially with regard to obtaining data on a center pivot position, tower velocity, and duty cycle. Choices of programming language and communication protocols have not yet been made.

COMPLETION SCHEDULE

A prototype of one segment of a three-manifold water application system developed by University of Georgia personnel has been constructed and testing is in progress. This system will be installed on one of the center pivot system in March 1995 (prior to growing season). Likewise, the control system will also be developed and installed in March 1995, although the control system and installed spatially-indexed data base will probably be somewhat limited and rudimentary in operation. This system will be evaluated during the 1995 growing season in an experiment in which both water and nutrients (nitrogen) will be applied. The capability to apply nutrients instantaneously at a range of rates probably will not be available during the initial evaluation period, but a rudimentary system for applying incremental nitrogen for a limited range of rates should be available. During and following this evaluation period, the system will be modified, upgraded, and improved as technology is developed and incorporated in the system design.

ACKNOWLEDGMENT

The authors gratefully acknowledge contributions of the other members of the Irrigation System Design Team: W. J. Busscher, R. D. Bender, D. E. Evans, P. G. Hunt, K. C. Stone, and L. J. Usrey.

REFERENCES

1. Duke, H. R., D. F. Heermann, and C. W. Fraisse. 1992. Linear move irrigation system for fertilizer management research. Proc. International Exposition and Technical Conference, The Irrigation Association. p 72-81.

2. Fraisse, C. W., D. F. Heermann, and H. R. Duke. 1992. Modified linear move system for experimental water application. Advances in planning, design, and management of irrigation systems as related to sustainable land use. Leuven, Belgium. Vol 1, p 367-376.

3. Lyle, W. M. 1992. Personal Communication. Manifold systems for achieving variable-rate water and chemical applications on center pivot and linear irrigation machines.

4. Lyle, W. M., and J. P. Bordovsky. 1981. Low energy precision application (LEPA) irrigation system. Trans. of the ASAE 24(5):1241-1245.

5. Lyle, W. M., and J. P. Bordovsky. 1983. LEPA irrigation system evaluation. Trans. of the ASAE 26(3):776-781.

6. McCann, I. R., and J. C. Stark. 1993. U. S. Patent No. 5,246,164 "Method and apparatus for variable application of irrigation water and chemicals", dated September 21, 1993.

7. Sadler, E. J., W. J. Busscher, and D. L. Karlen. 1994. Site-specific yield histories on a SE coastal plain field. Site-specific Management for Agricultural Systems Proceedings, 2nd Int'l. Workshop, March, 1994, Bloomington, MN. (In press).

8. Stark, J. C., I. R. McCann, B. A. King, and D. T. Westermann. 1993. A two-dimensional irrigation control system for site-specific application of water and chemicals. Agronomy Abstracts 85:329.

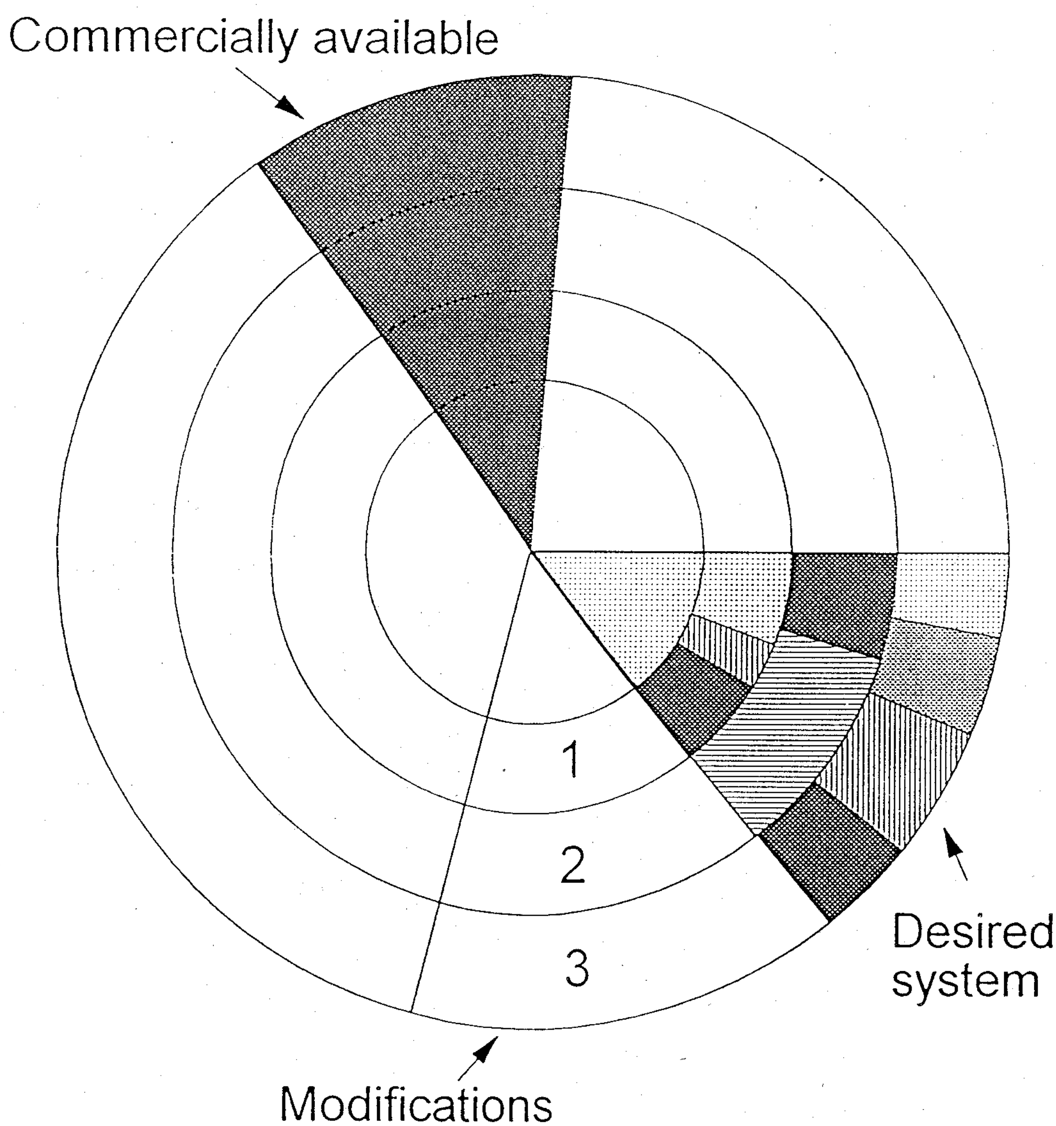

Figure 1. Schematic diagram of commercial center pivot irrigation system and modifications to achieve site-specific water and chemical applications.

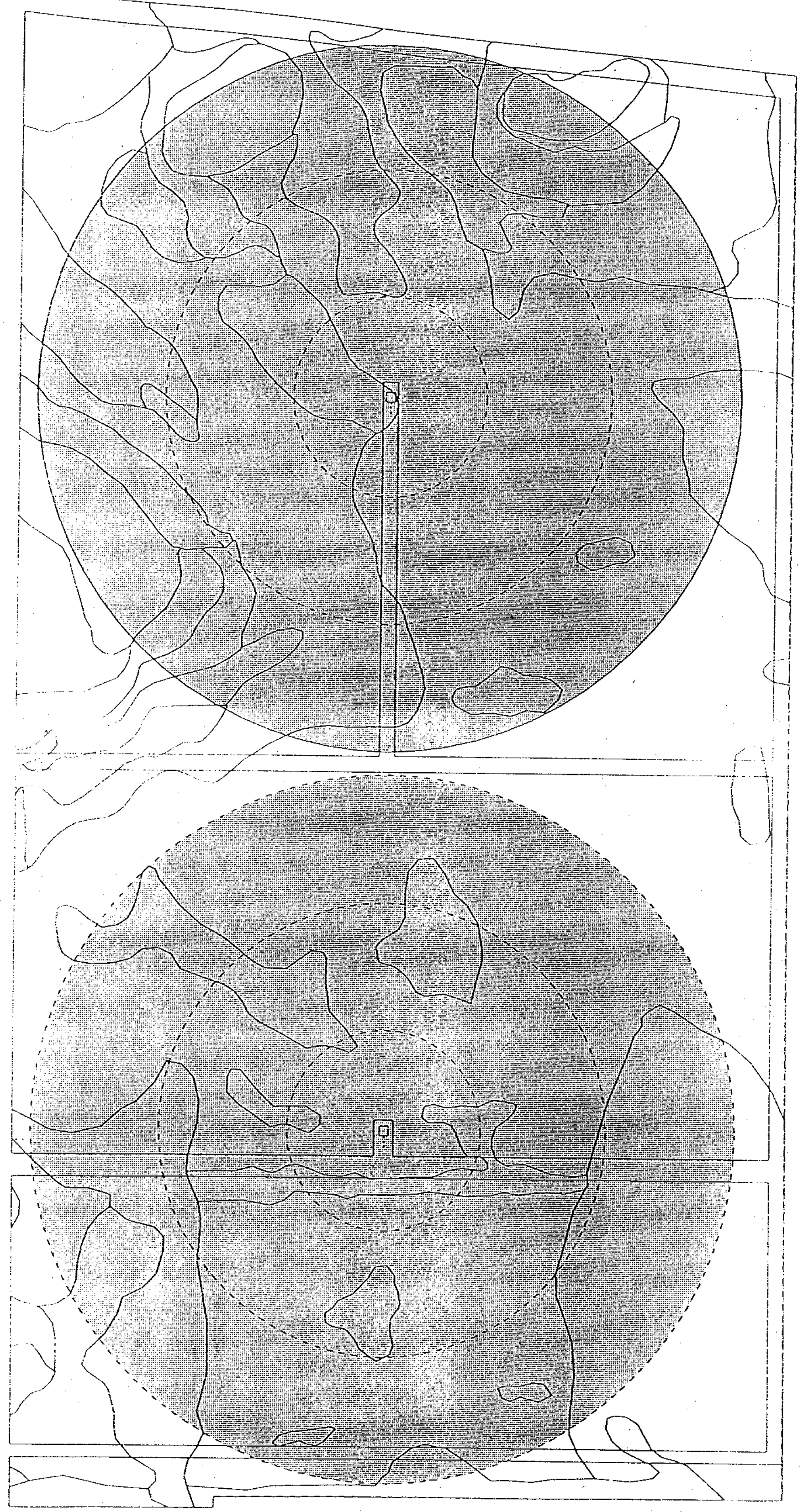

Figure 2. Map of experimental area at Coastal Plains Soil, Water, and Plant Research Center, Florence, South Carolina, showing location of two center pivot irrigation system and soil boundaries.